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(54) Method for investigating drag and torque loss in the drilling process.

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IADC/SPE 11380 DRILLING CONFERENCE, New Orleans, Louisiana, 20th-23rd February 1983, pages 201-206, SPE, Dallas, Texas, US; C.A. JOHANCSIK et al.: "Torque and drag in directional wells - prediction and measurement"

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Description

This invention relates to the field of measurements while drilling, and more specifically to planning and analysis of the drilling process.

Drag and torque loss affect the drilling of all hydrocarbon wells, and are especially problematic in deviated wells. Drag manifests itself as an extra load over and above the rotating string weight when tripping out of the hole. Torsional loss from the rotating drill string while drilling causes the power available for rock destruction to be considerably lower than that applied at the rotary table. Problems of drag and torque loss normally occur together and can be particularly marked in long reach wells.

There are a variety of sources of drag and torque loss including differential sticking, keyseating, hole instabilities, poor hole cleaning, and the frictional interaction associated with side forces along the drill string. The side force profile is essentially determined by well geometry, and can be broadly divided into the effects of poor hole conditions or inappropriate mud weight, and effects of the well path itself.

U.S. Patent No. 4,549,431 to Soeiinah (assigned to Mobil Oil Corporation) discloses a method of detecting some of these problems in the drilling of a well from uphole measurements of hook load and free rotating torque. But experience has shown that noticeable differences occur between the torque and weight applied at the surface and that effectively applied at the bit, especially in areas of potential drilling problems. Likewise, the hookload values and the weight of the drill string in mud usually differ. Thus, the technique of the Soeiinah patent has serious inherent limitations.

The 1983 paper, "Torque and Drag in Directional Wells -- Prediction and Measurement," by C. A. Johancsik, D. B. Friesen, and Rapier Dawson (IADC/SPE 1983 Drilling Conference, Paper No. 11380), proposed a computer model of drill string torque and drag, but like the Soeiinah method, this model suffers from failure to analyze downhole torque and weight parameters.

Because the available techniques lack a way of investigating and analyzing downhole torque and weight on bit, which may differ significantly from the corresponding surface measurements of torque and hookload, there remains a gap between planned optimization of a drilling program and its implementation. Thus, a need has arisen for a new technique by which torque and weight transfer along the drill string can be analyzed, both in real-time for diagnosis of drilling problems and in advance for planning.

In a preferred embodiment of the invention, the conditions under which an earth boring apparatus such as a conventional drill bit operates are analyzed by measuring the torque applied at the surface to the drill string and the effective torque acting on the drill bit. The applied torque and effective torque are compared to determine torque loss. Likewise, applied weight on the drill string and effective weight acting on the drill bit may be measured and compared to determine drag losses. These measurements and comparisons may be done in real-time to diagnose unfavorable drilling conditions, or to assist the driller in decisions such as whether to trip out to change a bottom hole assembly, or to attempt a hole cleaning process such as a wiper trip, or to perform other procedures. The torque or weight measurements may be used to calculate a variable coefficient of friction acting on the drilling string. Trends in the torque or weight losses, or in the value of the coefficient of friction, may be observed on a plot of these quantities as a function of depth.

In addition to this real-time analysis, it is a further embodiment of the invention to plan or predict what is to be expected in a drilling process by assuming predetermined values for the coefficient of friction for the hole as a function of depth and calculating therefrom the torque and drag losses which are to be expected.

The present invention thus provides a method for analyzing torque and weight transfer along a drill string, to give the driller an enhanced insight into drilling efficiency and problem situations in the drilling process. In a preferred embodiment of the invention, the real-time analysis may be performed with the bit on bottom by detecting and interpreting trends of abnormal torque transfers. Abnormal weight transfers are analyzed based on hookload and weight transfer analysis. These techniques can be used alone or in combination to diagnose and quantify drilling problems related to drag and torque loss.

As a planning tool, the techniques of the present invention produce expected trends for weight and torque transfers in a given environment including the well profile, the bottom hole assembly design, the lithological sequence and the mud program. Weight and torque losses for several such drilling plans may be calculated, so that the most favorable plan may be chosen.

FIGURE 1 shows a preferred embodiment of an apparatus according to the present invention as it may appear while practicing the method of a preferred embodiment of the invention while drilling;

FIGURE 2 shows a schematic diagram of a torque and tension model as used in the preferred embodiment of the invention;

FIGURE 3 is an isometric view of a preferred embodiment of a force measuring means in the Figure 1 embodiment;

FIGURE 4 is a schematic representation of the force measuring means shown in FIGURE 3 showing preferred locations for various sets of force sensors and bridge circuits associated with these sensors;

FIGURE 5 is an enlarged view of one portion of the force measuring means of FIGURE 2 illustrating a preferred mounting arrangement for the force sensors;

FIGURE 6 shows a log of data obtained in a well with an apparatus and method according to a preferred embodiment of the invention;

FIGURE 7 shows a log of weight and torque losses; and

FIGURE 8 shows a log correlating weight and torque loss to drilling practices, lithology and bottomhole assembly.

FIGURE 9 shows a graphical representation of calculations of various load parameters in accordance with the present invention.

Turning now to Figure 1, an apparatus suitable for performing a method according to a preferred embodiment of the invention includes a measurement-while-drilling (MWD) tool 10 dependently coupled to the end of a drill string 11 comprised of one or more drill collars 12 and a plurality of tandemly connected joints 13 of drill pipe. Earth boring means, such as a conventional drill bit 14, are positioned below the MWD tools. The drill string 11 is rotated by a rotary table 16 on a conventional drilling rig 15 at the surface. Mud is circulated through the drill string 11 and bit 14 in the direction of the arrows 17 and 18.

As depicted in Figure 1, the tool 10 further comprises a plurality of heavy walled tubular bodies which are tandemly coupled to enclose weight and torque measuring means 20 adapted for measuring the torque and weight acting on the drill bit 14, as well as typical position measuring means 21 adapted for measuring parameters such as the direction and inclination of the tool 10 so as to indicate its spatial position. Typical data signaling means 22 are adapted for transmitting encoded acoustic signals representative of the output of the sensors 20 and 21 to the surface through the downwardly flowing mud stream in the drill string 11. These acoustic signals are converted to electrical signals by a transducer 34 at the surface. The electrical signals will be analyzed by appropriate data processing means 33 at the surface.

Conventional sensors for measuring hookload and torque applied to the drill string, 36 and 37 respectively, are located at the surface. A total depth sensor (not shown) is provided to allow for the correlation of measurements made during the drilling and tripping modes.

Turning now to FIGURE 3, the external body 24 of the force-measuring means 20 of a preferred embodiment is depicted somewhat schematically to illustrate the spatial relationships of the measurement axes of the body as the force-measuring means 20 measure weight and torque acting on the drill bit 14 during a typical drilling operation. Rather than making the force-measuring means 20 an integral portion of the MWD tool 10, in a preferred embodiment, the thick-walled tubular body 24 is cooperatively arranged as a separate sub that can be mounted just above the drill bit 14 for obtaining more accurate measurements of the various forces acting on the bit. It will, or course, be appreciated that other types of housings such as, for example, those shown in U.S. Patent No. 3,855,857 or U.S. Patent No. 4,359,898 could be used as depicted there or with modifications as needed for devising alternative embodiments of force-measuring apparatus suitable for use in the appartus and method of the present invention.

As seen in FIGURE 3, the body 24 has a longitudinal or axial bore 25 of an appropriate diameter for carrying the stream of drilling mud flowing through the drill string 11. The body 24 is provided with a set of radial openings, B1, B2, B3 and B4, having their axes all lying in a transverse plane that intersects the longitudinal Z-axis 26 of the body. It will, of course, be recognized that in the depicted arrangement of the body 24 of the force-measuring means 20, these openings are cooperatively positioned so that they are respectively aligned with one another in the transverse plane that perpendicularly intersects the Z-axis 26 of the body. For example, as illustrated, one pair of the holes B1 and B3, are respectively located on opposite sides of the body 24 and axially aligned with each other so that their respective central axes lie in the transverse plane and together define an X-axis 27 that is perpendicular to the Z-axis 26 of the body. In like fashion, the other two openings B2 and B4 are located in diametrically-opposite sides of the body 24 and are angularly offset by 90 degrees from the first set of openings B1 and B3 so that their aligned central axes respectively define the Y-axis 28 perpendicular to the Z-axis 26 as well as the X-axis 27.

Turning now to FIGURE 4, an isometric view is shown of the openings B1-B4, the X-axis 27, the Y-axis 28 and the Z-axis 26. As depicted, to measure the longitudinal force acting downwardly on the body member 24 in order to determine the effective weight-on-bit, force-sensing means are mounted in each quadrant of the openings B1 and B2. To achieve maximum sensitivity, these force-sensing means (such as typical strain gauges 401a-401d and 403a-403d) are respectively mounted at the 0-degrees, 90-degrees, 180-degrees and 270-degrees positions within the openings B1 and B3. In a like fashion, to measure the rotational torque imposed on the body member 24, rotational force-sensing means, such as typical strain gauges 402a-402d and 404a-404d, are mounted in each quadrant of the openings B2 and B4. As depicted, it has been found that maximum sensitivity is provided by mounting the strain gauges 402a-402d at the 45-degrees, 135-degrees, 223-degrees and 315-degrees positions in the opening B2 and by mounting the other strain gauges 404a-404d at the same angular positions in the opening B4. Measurement of the weight-on-bit is, therefore, obtained by arranging the several strain gauges 401a-401d and 403a-403d in a typical Wheatstone bridge B1-B3 to provide corresponding output signals (i.e., WOB). In a like manner, the torque measurements are obtained by connecting the several gauges 402a-402d and 404a-404d into another bridge B2-B4 that produces corresponding output signals (i.e., torque).

Those skilled in the art will, of course, appreciate that the several sensors described by reference to FIGURE 3 along with other force measuring sensors as desired for other purposes, can be mounted in various arrangements on the body 24. However, it has been found most advantageous to mount the several force sensors in the openings B1-B4 in such a manner that although the force sensors in a given opening are separated from one another, each sensor is located in an optimum position for providing the best possible response. For example, as depicted in the developed view of the opening B1 seen in FIGURE 5, the force sensors 401a and 401b are each mounted at their respective optimum locations in the same openings as are the torque sensors 402a-402d. It will, or course, be recognized that the several sensors located in the opening B1 are each secured to the body 24 in a typical manner such as with a suitable adhesive. Other sensors 201a and 201b for example, may also be so mounted. As illustrated, in the preferred arrangement of the force-measuring means 20 it has also been found advantageous to mount one or more terminal strips 31 and 32 in each of the several openings to facilitate the interconnection of the force sensors in any given opening to one another as well as to provide convenient terminal that will facilitate connecting the sensors to various conductors 33 leading to the measuring circuitry in the MWD tool 10 (not seen in FIGURE 5).

As is typical, it is preferred that the several force sensors be protected from the borehole fluids and the extreme pressures and temperatures normally encountered in boreholes by sealing the sensors within their respective openings B1-B4 by means of typical fluid-tight closure members (not shown in the drawings). The enclosed spaces defined in these openings and their associated interconnecting wire passages are usually filled with a suitable oil that is maintained at an elevated pressure by means such as a piston or other typical pressure-compensating member that is responsive to borehole conditions. Standard feed through connectors (not shown in the drawings) are arranged as needed for interconnecting the conductors in these sealed spaces with their corresponding conductors outside of the oil-filled spaces.

Turning now the principles of operation of the present invention, in a preferred embodiment, torque and weight transfer are analyzed using a dynamic torque and tension model diagrammed in FIGURE 2. In this model, a tension T and torque TOR act on the downhole end of an incremental length of drill string 40, while an uphole tension T+dT and torque TOR+d(TOR) act on the uphole end. A buoyancy force Fb acts in an upward vertical direction while a gravitational force Fg acts in an opposing direction. These forces all contribute to a resultant side force Tn acting in a direction perpendicular to a plane tangent to the incremental drill string length 40.

The side force Tn given by the equation

$$Tn=[(T\ d\theta - W\sin\theta)^2 + (T\ d\phi \sin\theta)^2]^{\frac{1}{2}} \tag{1}$$

where dθ = inclination change, dϕ = azimuth change, and W = bouyant weight of the drill string (Fg - Fb). This equation can be solved by iterative methods well-known in the art.

An additional side force component due to stiffness of the drill string can be computed using the theory of bending and twisting of elastic rods. Models using such theories are known to those having ordinary skills in the art, and are contained in the literature associated with this field. One such model is discussed in Jogi et al, "Three Dimensional Bottomhole Assembly Model Improves Directional Drilling," SPE Paper No. 14768, February, 1986. This component may, if desired, be added to Tn in equation (1) to correct for stiffness of the drill string.

A drag force acts along the length of the drill string increment 40, and is assumed to be proportional to the side force Tn acting on the drill string. The proportionality coefficient μ(s) (which is not necessarily constant but may be a function of the distance s from the bit) appears in this model as a sliding friction coefficient. The resulting frictional force u(s)Tn acts against the motion of the drill string increment 40, leading to drag while tripping out and torque lose while rotating.

The friction profile μ(s) can be calculated on an <u>incremental</u> basis as follows:

Consider that the well has been drilled to some pipe depth D and that the friction $\mu_D(s)$ down to this point is known (having been calculated in previous increments). The well is now drilled to a pipe depth D+O and the friction coefficient μ_O for this last segment is to be calculated (we must assume the μ_O is a constant over this last segment). The effective tension while rotating, at some height s above the bit is given by

$$T(s) = -DWOB + \int_{bit} W(\bar{s})\ \cos\theta(\bar{s})ds \tag{2}$$

where DWOB is the downhole weight on bit, W ($\bar{s}$) is the buoyed weight per unit length of the tubulars and θ ($\bar{s}$) is the inclination at $\bar{s}$ obtained from survey data ($\bar{s}$ is an integration variable ranging from zero to s).

The side force at s, which is Tn(s), can now be calculated from equation (1) using equation (2) in conjunction with the survey data.

The torque lost between surface and the bit is given by

$$\mathrm{STOR} - \mathrm{DTOR} = \int_{\mathrm{bit}}^{\mathrm{surface}} \mu(s)\cdot \mathrm{Tn}(s)\ R(s)ds$$

$$= \int_{\mathrm{bit}}^{D} \mu_{l}\,\mathrm{Tn}(s)\ R(s)ds \quad + \quad \int_{D}^{\mathrm{surface}} \mu_{D}(s)\ \mathrm{Tn}(s)\ R(s)ds \tag{3}$$

where
s = height above the bit
R(s) = active radius of tubulars
STOR = surface torque
DTOR = effective bit torque
and where $\mu_D(s)$ is known. Equation (3) thus provides a means of calculating μ_O so that the friction profile is now known (at least piecewise) to the new depth D+o. This updated profile is then incorporated in the next increment when the well has reached a pipe depth D+2o.

It should be noted that a significant contrast will be expected between friction coefficients for open and cased hole. In particular it will be necessary to recalculate $\mu(s)$ when casing is set. This can be done by assuming that the new length of casing is characterized by a fixed coefficient u which is calculated, as described above, when drilling commences after the casing is set.

Once $\mu(s)$ is determined the overpull when tripping can be calculated. (This will be of substantial value for estimating the overpull for planned wells and may be used to aid in the design of well trajectories). While tripping out of hole the incremental change in effective tension ΔT for a pipe increment of length Δs is given by

$\Delta T = \Delta s\ W(s) \cos \theta(s) + \mu(s)\ \mathrm{Tn}(s)(4)$

Given $\mu(s)$ then equations (1) and (4) provide the elements of an incremental (generally numerical) solution for the effective tension T(s). The evaluation of T(s) at the surface gives the hook load, and the overpull is the difference between the hook load and the free rotating weight of the drill string.

As distinct from the proposals of Johancsik et al who, in the above-referenced paper, define a global coefficient of friction, a preferred embodiment of the invention described here proposes a running calculation of the friction profile $\mu(s)$. This has the effect of generating a far more sensitive characterization of the frictional effects than is provided by the global friction approach which effectively smears local effects over the entire drill string.

This quantity μ yields useful information about how drilling is progressing. For example, if the bottom hole assembly remains unchanged, then an increase in the coefficient of friction μ indicates a change in hole condition, hole shape or lithology, or a malfunction of the bottom hole assembly. The quantity μ is preferrably calculated and recorded as a function of depth while drilling (or tripping) progresses, to produce a log useful in the diagnosing of drilling or well bore problems.

Values for HKLD and DWOB, as well as STOR and DTOR, can be compared at successive depths to determine torque and weight losses. Such losses, as is the quantity μ, are preferably correlated with depth and recorded as a function of depth on a log. Trends and changes can then be observerd.

FIGURES 6, 7 and 8 show an illustrative example of how a method according to a preferred embodiment of the invention may be used. These figures show logs obtained according to a preferred embodiment of the present invention in a relatively straight well having a constant inclination.

The following data is shown on the DATA log of FIGURE 6:

Track 1: mud weight in (MWTI), total hook load (THKD), and off-bottom time (OBTI);
Track 2: flow rate (RPM) in rotations per minute;
Track 3: gamma ray (GR) and rate of penetration averaged over 1.524 meter (five foot) intervals (ROPS);
Track 4: off-bottom flag (OBFL); downhole weight on bit (DWOB); surface weight on bit (SWOB);
Track 5: off-bottom flag (OBFL); downhole torque (DTOR); surface torque (STOR).

FIGURE 7 shows a log of weight and torque losses, computed from inputs taken from the DATA log of Figure 6. Track 1 of the WEIGHT AND TORQUE LOSSES log shows the calculated free rotating hookload (THDC). Track 2 shows the weight-on-bit losses between surface and downhole (WODC). The best weight transfer is achieved in the section from A–A to B–B when WODC is minimal. The torque transfer (TODM), the difference between the measured surface torque and the measured downhole torque, is shown in Track 3.

Referring now to FIGURE 8, the ANALYSIS log was produced in order to investigate explanations for weight-on-bit and torque transfer problems related to hole stability and crookedness. Correlations were sought between weight-on-bit and torque transfer and drilling practice (especially off bottom periods between the drilling sequences), lithology, and bottomhole assembly configuration.

The following variables already defined in the previous logs are shown in FIGURE 8:

Track 1: mud weight in, total hookload and free rotating string weight;
Track 2: rpm and flow rate;
Track 5; gamma ray and rop; and
Track 4: weight-on-bit loss

The calculated variables shown in this log are:

Track 1: off bottom flag each time the bit has been taken off bottom (OBFL);
Track 2: off bottom pumping time up to 20 min. (OBPT);
Track 3: friction factor (FFCS) calculated with the torque losses from bit to surface;
Track 6: friction factor correlation (FFDC) calculated with the WOB losses (WODC) from bit to surface.

The ANALYSIS leg in FIGURE 8 clearly shows the effectiveness of the reaming when the joint is drilled out in the WODC track, which shows an improved weight transfer when the drilling is resumed at C-C. This log also shows that the weight-on-bit transfer is better in the less argileaous sections up to C-C. The transfer decreases when the clay content increases between C-C and D-D. A circulation exceeding 20 minutes was done at C-C is shown to drastically increase the transfer, Off bottom time at C-C exceeded 50 minutes, for a wiper trip. The C-C level is also the level where the last stabilizer reached a cleaner limestone section starting at B-B. Trends can be seen on the log which reflect the overall interaction between the borehole walls and the drillstring.

The ANALYSIS log shows the friction factor correction FFDC due to weight-on-bit loss to be, in effect a normalization of the weight-on-bit transfer WODC, since the FFDC track follows the trends of the weight-on-bit transfer track.

Between E–E and F–F, there is a constant decrease of the weight-on-bit transfer while a single joint is drilled. Nine hundred and seven kilograms (two thousand pounds) are regularly lost between the beginning and the end of the kelly length drilled out.

At G–G, a complete WOB transfer was obtained. This corresponds to a connection with a 10-minute circulation. The 15-minute reaming operation was particularly efficient due to an increased flow rate used at this point. This beneficial effect is also noted in the friction factor decrease. It shows also that the benefit of this procedure lasted only for 13.7 meters (45 feet). This kind of information will be useful to a driller in deciding whether to perform such procedures.

Turning now to another embodiment of this invention, Equations (2) and (3) can be used for well planning by assuming a constant value for μ over a portion of a well and calculating the torsional and drag losses which should be expected for a given trajectory. The assumed value for μ may be chosen from knowledge of wells in similar lithologies, as in the case of multiple wells drilled from a single platform. Alternatively, a value of 0.3 as an estimate of μ has been found to work satisfactorily for comparison purposes where torque and drag losses for several trajectories are computed and compared to determine the optimal trajectory. It would also be possible to assume a particular functional form for $\mu(s)$ and an initial value to arrive at torque and drag loss.

FIGURE 9 shows an example of a graphical representation of calculation results which is useful in well planning. In the particular example presented, trends in the torque and weight parameters are shown for the drilling ahead of a well from 2,286 meters (7,500 feet) to 4,572 meters (15,00 feet). The coefficient of friction was assumed to be a constant 0.3, while weight-on-bit was taken to be a constant 13,608 kilograms (30 kilopounds). The weight transfer was assumed complete, so that the surface and downhole weight-on-bit are the same. The buoyant drill string weight, i.e., the weight of the drill string immersed in mud, was calculated and is indicated by curve 42. The rotating string load, indicated by curve 43, is the drill string tension under the hook while rotating. This quantity includes the effect of inclination of sections of the well. The increase in buoyant weight and rotating string load is linear due to the addition of a single type of drill pipe while drilling this portion of the well. The torque losses represent the difference between the surface and the downhole torque. The shape of the torque loss curve 44 is due to different grades of drill pipe used within the string. For example, the section of lower increase in torque loss (2,895 meters to 3,810 meters or 9,500 feet to 12,500 feet) shows the effect of using 914 meters (3,000 feet) of aluminium drill pipe within the string. Thus, the expected loads and torque losses for a particular drill string and bottomhole assembly can be predicted, and the appropriateness of particular equipment configurations can be assessed.

Claims

1. A method for investigating conditions under which a drill string 11 and a drill bit 14 excavate a borehole, wherein a surface measurement representative of the torque or the hookload of the drill string 11 is repeatedly measured at the earth's surface as the drill bit passes successive depths in the borehole;
the method characterized by the following steps:
substantially simultaneously with the above surface measurement, making a downhole measurement representative of the effective torque or the weight on bit acting on the drill bit 14; and
comparing the surface and downhole measurements representative of the measured hookload and weight on bit to determine drag loss as a function of depth, or representative of the measured applied torque and effective torque to determine the mount of torque lost as a function of depth as the applied torque is transferred down the drill string 11.

2. The method of claim 1 .in which the applied torque and effective torque are measured, further comprising the step of determining from these measurements a coefficient of rotating friction acting between the borehole and the drill string 11.

3. The method of claim 1 or 2, in which the hookload and weight on bit are measured while drilling further comprising the step of determining from these measurements a coefficient of sliding friction acting between the borehole and the drill string.

4. The method of claim 2 or 3 further including the steps of:
deriving an indication of the path followed by said drill string in said borehole;
determining an indication of tension in the drill string;
in response to said indications of tension and drill string path, determining an indication of side force acting on said drill string; and
in response to said indications of side force and said surface and downhole measurements, determining said sliding or rotating friction coefficient.

5. The method a recited in claim 4 wherein said step of determining tension includes the steps of:
deriving a measurement of weight on bit in the vicinity of the bit;
determining an indication of the buoyed weight of said drill string; and
in response to said measurement of weight on bit, said indication of buoyed weight and said drill string path, determining the tension of the drill string.

6. The method of claim 4 wherein said steps are repeated at each of a plurality of positions as the depth of the drill string in the well is varied to obtain a depth varying indication of the friction coefficient.

7. The method as recited in claim 6 wherein said steps are repeated over a cased section of said borehole in order to correct the depth varying indication of the friction coefficient for the effects of caing.

8. The method as recited in claim 6 wherein said depth varying indication of the friction coefficient is monitored to reveal actual or potential problems with the process of drilling the well.

9. The method as recited in one of claims 4 to 8 further including the step of calculating hookload expected in tripping out of the borehole in response to said indication of the friction coefficient to identify potential overpull events.

10. The method as recited in one of claims 4 to 9 further including the step of determining the configuration of the bottom hole assembly and in response to said configuration and to said friction coefficient, predicting overpull or sticking as a function of drill string position.

11. The method as recited in one of claims 4 to 10 further including the step of evaluating a proposed well plan in response to said indication of friction coefficient.

12. The method as recited in claim 11 wherein the step of evaluating a proposed well plan includes the following steps:
a. designing a proposed well geometry;
b. designing a proposed drilling plan including determining a proposed bottom hole assembly configuration; and
c. calculating indications of torque transfer and weight on bit transfer in response to said friction coefficient, said proposed well geometry and said bottom hole assembly configuration.

Patentansprüche

1. Ein Verfahren für Untersuchung der Bedingungen, unter denen ein Bohrstrang 11 und ein Bohrkopf 14 ein Bohrloch abteufen, bei welchem eine Oberflächenmessung, repräsentativ für das Drehmoment oder die Hakenlast des Bohrstrangs 11 wiederholt an der Erdoberfläche gemessen wird, wenn der Bohrkopf aufeinanderfolgende Tiefen in dem Bohrloch durchteuft, welches Verfahren durch die folgenden Schritte gekennzeichnet ist:
Ausführen einer Teufenmessung im wesentlichen simultan mit den obigen Oberflächenmessungen, welche Teufenmessung repräsentativ ist für das wirksame Drehmoment oder die Kopfbelastung, die auf den Bohrkopf wirkt, und
Vergleich der Oberflächen- und Teufenmessungen, repräsentativ für die gemessene Hakenlast und die Kopfbelastung, zum Bestimmen des Schleppverlusts in Funktion der Tiefe, oder repräsentativ für das gemessene eingespeiste Drehmoment und das wirksame Drehmoment, zum Bestimmen der Höhe des

Drehmomentenverlusts in Funktion der Tiefe bei der Übertragung des eingespeisten Drehmoments längs des Bohrstrangs nach unten.

2. Das Verfahren nach Anspruch 1, bei dem das eingespeiste Drehmoment und das wirksame Drehmoment gemessen werden, das ferner den Schritt umfaßt, aus diesen Messungen einen Koeffizienten der Drehreibung zu bestimmen, der zwischen dem Bohrloch und dem Bohrstrang wirksam ist.

3. Das Verfahren nach Anspruch 1 oder 2, bei dem die Hakenlast und die Kopfbelastung während des Bohrens gemessen werden, das ferner den Schritt umfaßt, aus diesen Messungen einen Koeffizienten der Gleitreibung zu bestimmen, der zwischen dem Bohrloch und dem Bohrstrang wirksam ist.

4. Das Verfahren nach Anspruch 2 oder 3, ferner die Schritte umfassend:

Ableitung einer Indikation der Bahn, der der Bohrstrang im Bohrloch folgt,

Bestimmung einer Indikation der Spannung im Bohrstrang,

Bestimmung, in Abhängigkeit von den Indikationen der Spannung und der Bohrstrangbahn, einer Indikation von auf den Bohrstrang wirkenden Seitenkräften, und Bestimmung, in Abhängigkeit von den Seitenkraft-Indikationen und den Oberflächen- und Teufenmessungen, des Gleit- oder Drehreibungskoeffizienten.

5. Das Verfahren nach Anspruch 4, bei dem der Schritt der Spannungsbestimmung die Schritte umfaßt:

Ableitung einer Messung der Kopfbelastung in der Nähe des Kopfes,

Bestimmung einer Indikation des Auftriebsgewichts des Bohrstrangs, und

Bestimmung, in Abhängigkeit von der Kopfbelastungsmessung, der Auftriebsgewichtsindikation und der Bohrstrangbahn, der Spannung des Bohrstrangs.

6. Das Verfahren nach Anspruch 4, bei dem die Schritte bei jeder von einer Mehrzahl von Positionen wiederholt werden, wenn die Tiefe des Bohrstrangs im Bohrloch verändert wird, um eine tiefenvariable Indikation des Reibungskoeffizienten zu erhalten.

7. Das Verfahren nach Anspruch 6, bei dem die Schritte über einen ausgekleideten Abschnitt des Bohrlochs wiederholt werden, um die tiefenvariable Indikation des Reibungskoeffizienten bezüglich der Effekte der Auskleidung zu korrigieren.

8. Das Verfahren nach Anspruch 6, bei dem die tiefenvariable Indikation des Reibungskoeffizienten überwacht wird zum Erkennen aktueller oder potentieller Probleme bezüglich des Prozesses der Bohrlochabteufung.

9. Das Verfahren nach einem der Ansprüche 4 bis 8, ferner umfassend den Schritt der Berechnung der zu erwartenden Hakenlast beim Ausfahren aus dem Bohrloch in Abhängigkeit von den Reibungskoeffizientindikationen zum Identifizieren potentieller Zug-Überbelastungen.

10. Das Verfahren nach einem der Ansprüche 4 bis 9, ferner umfassend den Schritt der Bestimmung der Konfiguration der Grundloch-Baugruppe und, in Abhängigkeit dieser Konfiguration und des Reibungskoeffizienten, Vorausbestimmung von Zug-Überbelastung oder Festklemmen in Funktion der Bohrstrangposition.

11. Das Verfahren nach einem der Ansprüche 4 bis 10, ferner umfassend den Schritt der Bewertung eines vorgeschlagenen Bohrlochplans in Abhängigkeit von der Indikation des Reibungskoeffizienten.

12. Das Verfahren nach Anspruch 11, bei dem der Schritt der Bewertung eines vorgeschlagenen Bohrlochplans die folgenden Schritte umfaßt:

a. Aufzeichnen einer vorgeschlagenen Bohrlochgeometrie,

b. Aufzeichnen eines vorgeschlagenen Bohrplans einschließlich der Bestimmung einer vorgeschlagenen Grundloch-Baugruppenkonfiguration, und

c. Berechnen von Indikationen von Drehmomentübertragung und Kopfbelastungsübertragung in Abhängigkeit von dem Reibungskoeffizienten, der vorgeschlagenen Bohrlochgeometrie und der Grundloch-Baugruppenkonfiguration.

Revendications

1. Procédé pour étudier les conditions dans lesquelles un train de tiges 11 et un trépan 14 percent un trou ce sondage, une mesure en surface, représentative du couple ou de la charge de crochet du train de tiges 11 étant exécutée de façon répétée à la surface du sol lorsque le trépan franchit des profondeurs successives du trou de sondage;

le procédé étant caractérisé par les étapes suivantes consistant à:

effectuer, sensiblement en même temps que la mesure en surface indiquée précédemment, une mesure au fond du trou de sondage, représentative du couple effectif ou du poids agissant sur le trépan 14; et

comparer la mesure en surface et la mesure à l'intérieur du trou de sondage, représentatives de la charge mesurée appliqué au crochet et du poids appliqué au trépan, pour la détermination de la perte due à la résistance à l'avancement en fonction de la profondeur, ou représentatives du couple appliqué mesuré et du couple effectif pour déterminer la valeur de perte du couple en fonction de la profondeur lorsque le couple appliqué est transmis au train de tiges 11.

2. Procédé selon la revendication 1, selon lequel on mesure le couple appliqué et le couple effectif, et incluant en outre l'étape consistant à déterminer, à partir de ces mesures, un coefficient de frottement en rotation agissant entre le trou de sondage et le train de tiges 11.

3. Procédé selon la revendication 1 ou 2, selon lequel on mesure la charge appliquée au crochet et le poids appliqué au trépan lors du forage, et incluant en outre l'étape consistant à déterminer, à partir de ces mesures, un coefficient de frottement avec glissement présent entre le trou de sondage et le train de tiges.

4. Procédé selon la revendication 2 ou 3, incluant en outre les étapes consistant à :

obtenir une indication du trajet de déplacement suivi par ledit train de tiges dans ledit trou de sondage;

déterminer une indication de la tension dans le train de tiges;

en réponse auxdites indications de tension et de trajet de déplacement du train de tiges, déterminer une indication de la force latérale agissant sur ledit train de tiges; et

en réponse auxdites indications de la force latérale et de ladite mesure en surface et de ladite mesure au fond du trou de sondage, déterminer ledit coefficient de frottement avec glissement ou en rotation.

5. Procédé selon la revendication 4, selon lequel ladite étape de détermination de la tension inclut les étapes consistant à:

obtenir une mesure du poids appliqué au trépan au voisinage de ce dernier;

déterminer une indication de la force ascensionnelle appliquée audit train de tiges; et

en réponse à ladite mesure du poids appliqué au trépan, à ladite indication de la force ascensionnelle et audit trajet de déplacement du train de tiges, déterminer la tension dans le train de tiges.

6. Procédé selon la revendication 4, selon lequel on répète lesdites étapes en chacune d'une pluralité de positions, lorsque la profondeur du train de tiges dans le puits varie, pour obtenir une indication du coefficient de frottement, qui varie en fonction de la profondeur.

7. Procédé selon la revendication 6, selon lequel on répète lesdites étapes dans une section tubée dudit trou de sondage de manière à corriger l'indication du coefficient de frottement, qui varie en fonction de la profondeur, en rapport avec les effets du tubage.

8. Procédé selon la revendication 6, selon lequel on contrôle ladite indication du coefficient de frottement variant en fonction de la profondeur, pour déterminer l'existence de problèmes réels ou potentiels lors de l'opération de forage du puits.

9. Procédé selon l'une des revendications 4 à 8, incluant en outre l'étape consistant à calculer la charge du crochet, à laquelle on s'attend lors de la remontée et la sortie hors du trou de forage en réponse à ladite indication du coefficient de frottement, afin d'identifier ces éventuels suppléments de traction.

10. Procédé selon l'une des revendications 4 à 9, incluant en outre l'étape consistant à déterminer la configuration du dispositif situé au fond du trou et, en réponse à ladite configuration et audit coefficient de frottement, prédire une traction excessive ou un coincement en fonction de la position du train de tiges.

11. Procédé selon l'une des revendications 4 à 10, incluant en outre l'étape consistant à évaluer un tracé de puits proposé en réponse à ladite indication du coefficient de frottement.

12. Procédé selon la revendication 11, selon lequel l'étape d'évaluation d'un plan de puits proposé inclut les étapes suivantes consistant à:

a. concevoir une géométrie du puits proposée;

b. concevoir un plan de forage proposé incluant la détermination d'une configuration proposée du dispositif situé au fond du trou; et

c. calculer des indications du transmission de couple et du transmission de poids au trépan audit coefficient de frottement, à ladite géométrie de puits proposée et à ladite configuration du dispositif situé au fond du trou.

FIG.1

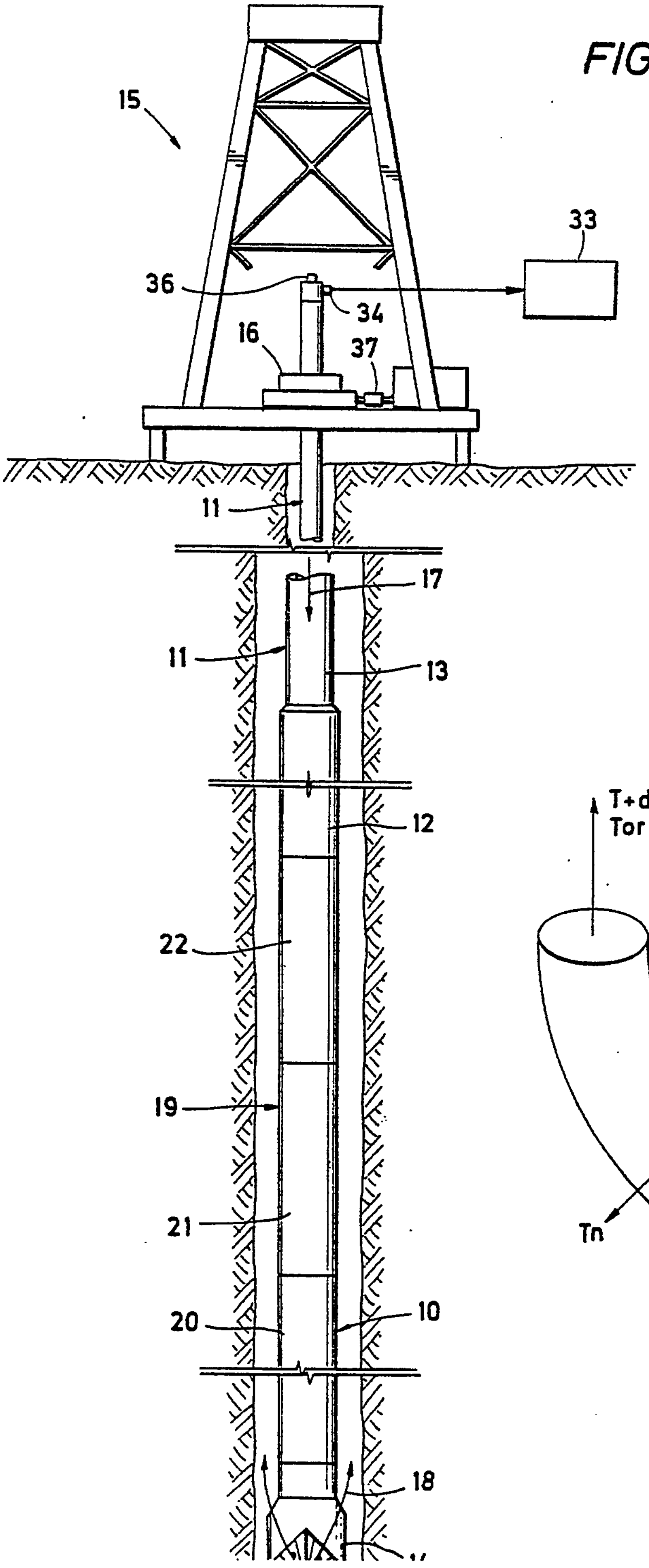

15
33
36
34
16
37
11
17
11
13
12
22
19
21
20
10
18

FIG. 2

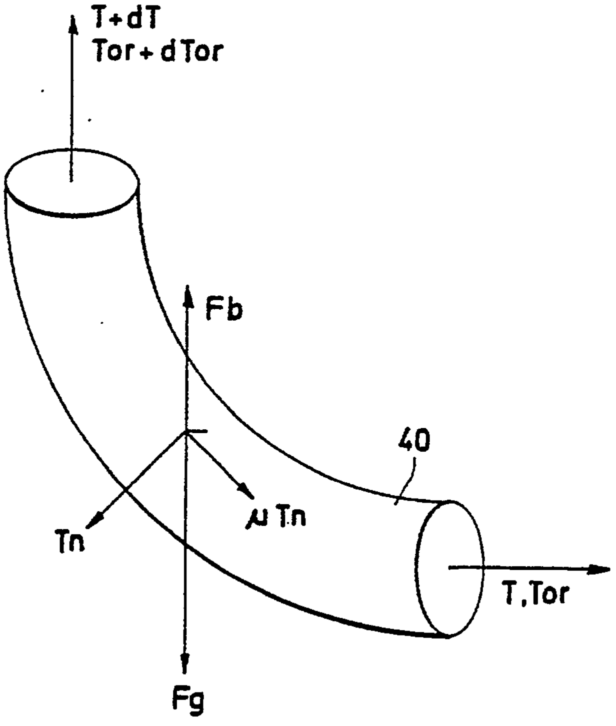
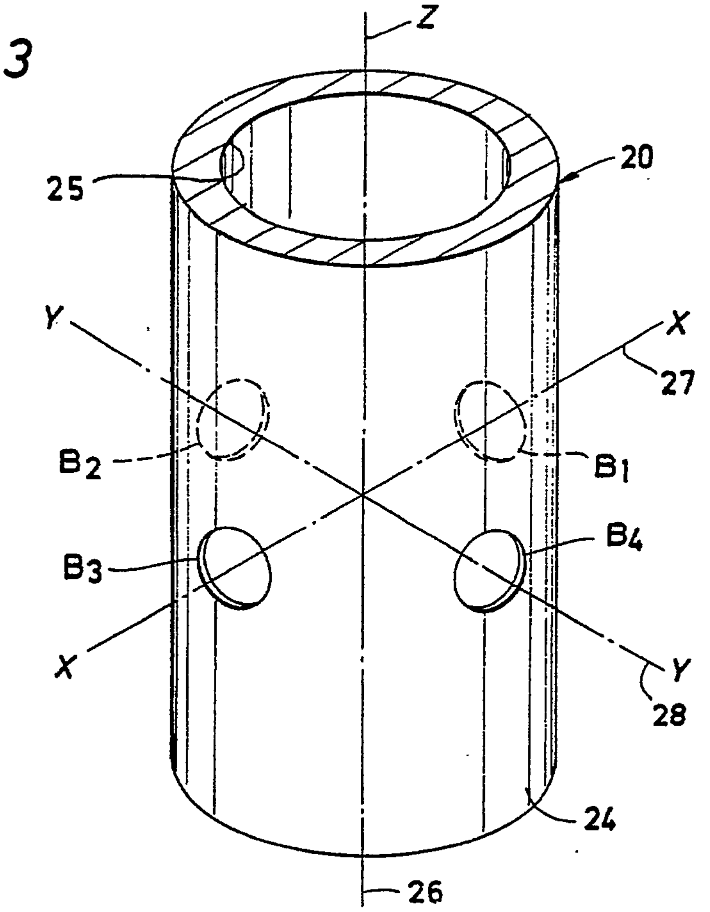

T+dT
Tor+dTor
Fb
40
Tn
μTn
T,Tor
Fg

FIG. 3


Z
20
25
Y
X
27
B2
B1
B3
B4
X
Y
28
24
26

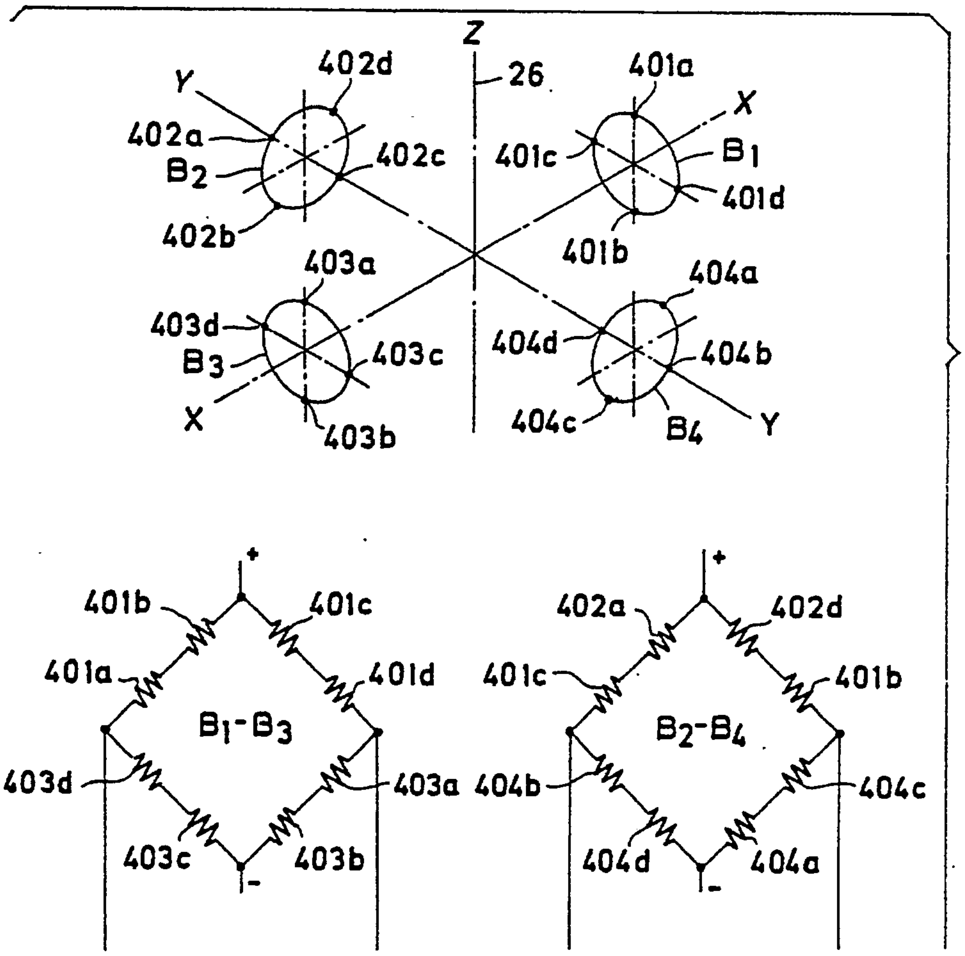

Z
26
Y
402d
402a
402c
B2
402b
401a
X
401c
B1
401d
401b
403a
403d
B3
403c
X
403b
404a
404d
404b
404c
B4
Y
+
401b
401c
401a
401d
B1-B3
403d
403a
403c
403b
-
+
402a
402d
401c
401b
B2-B4
404b
404c
404d
404a
-

FIG. 4

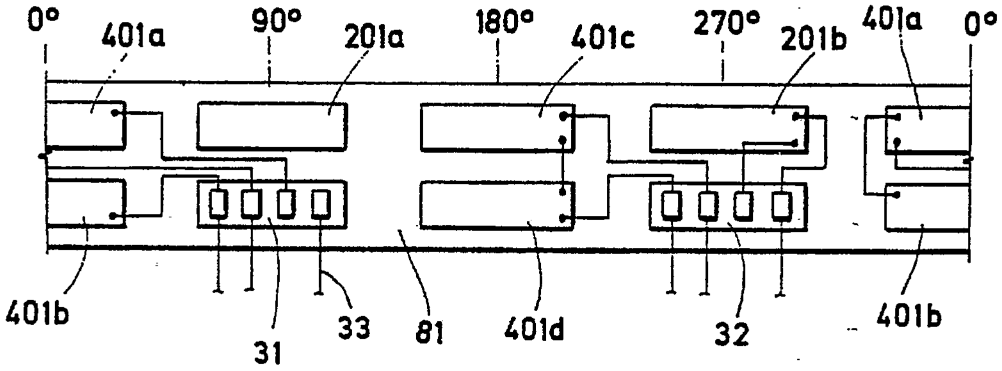
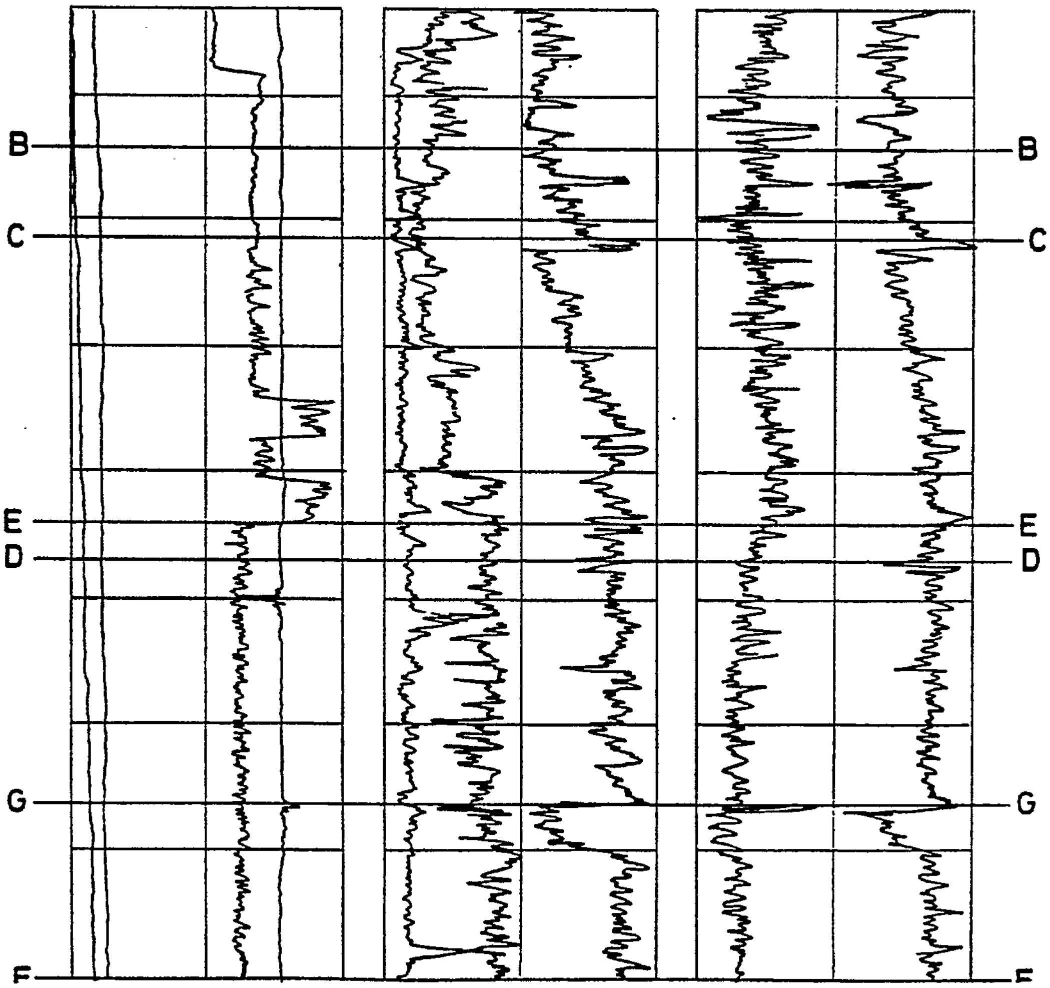

0°
401a
90°
201a
180°
401c
270°
201b
401a
0°
401b
31
33
81
401d
32
401b

FIG. 5

FIG. 8


B
C
E
D
G
F
B
C
E
D
G
F

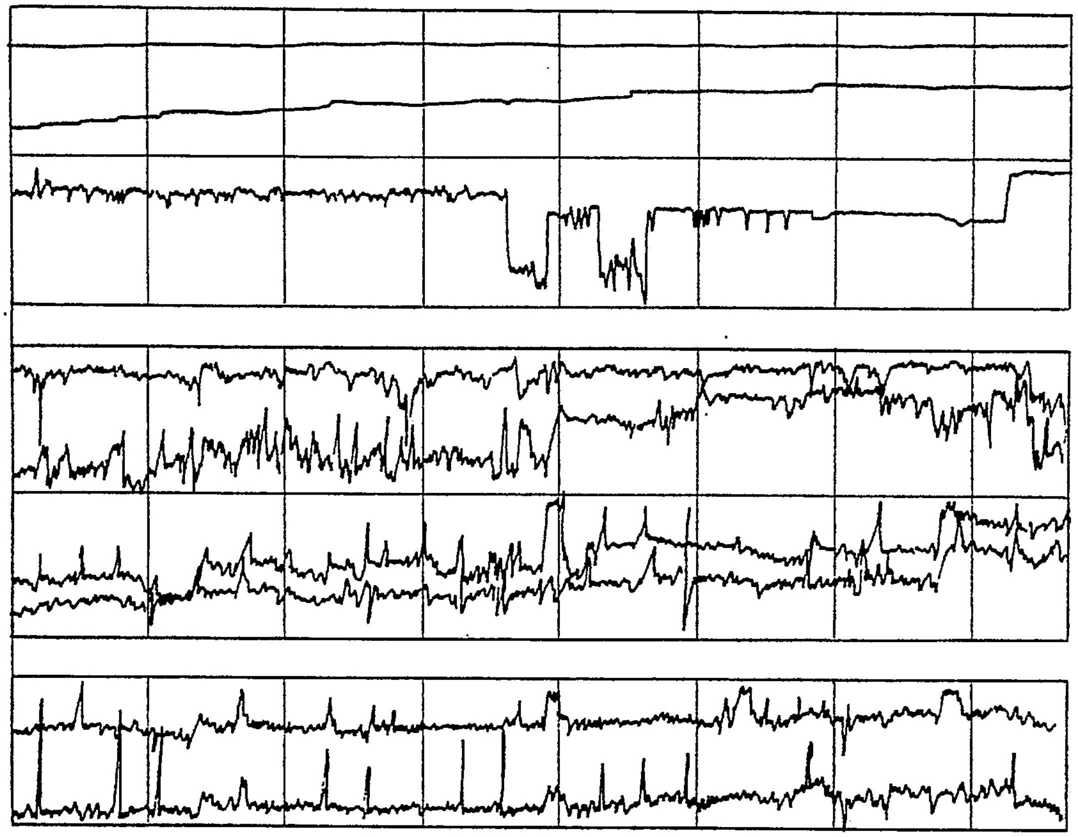


FIG.6

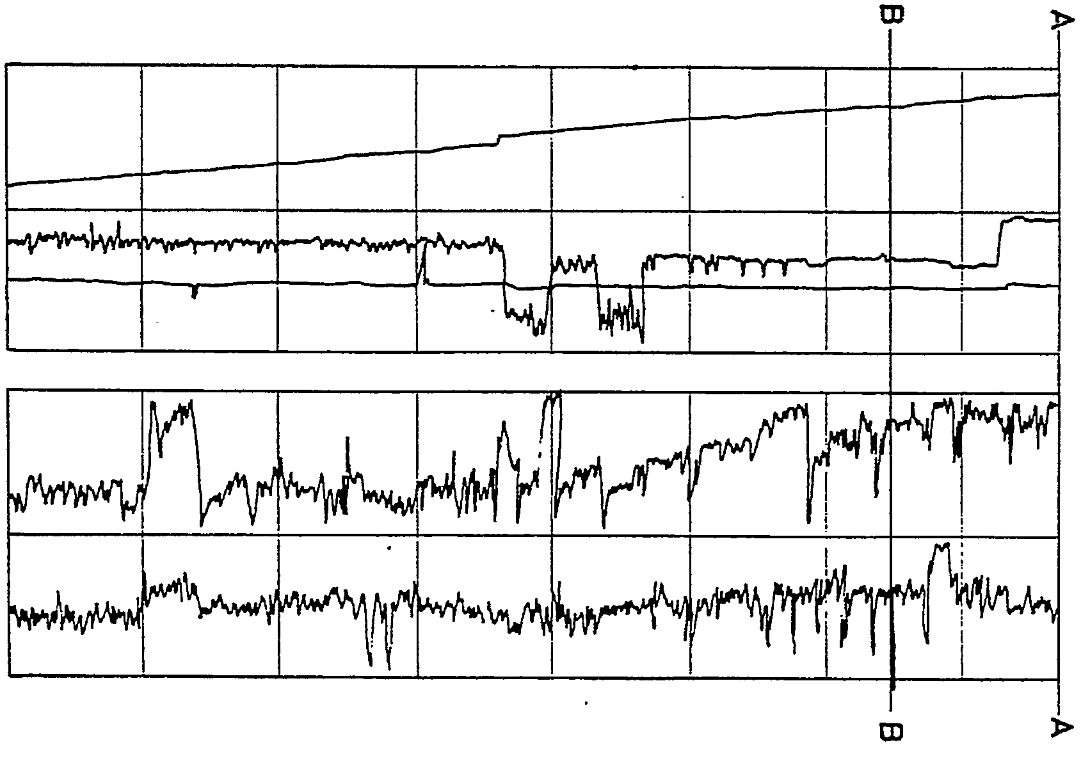
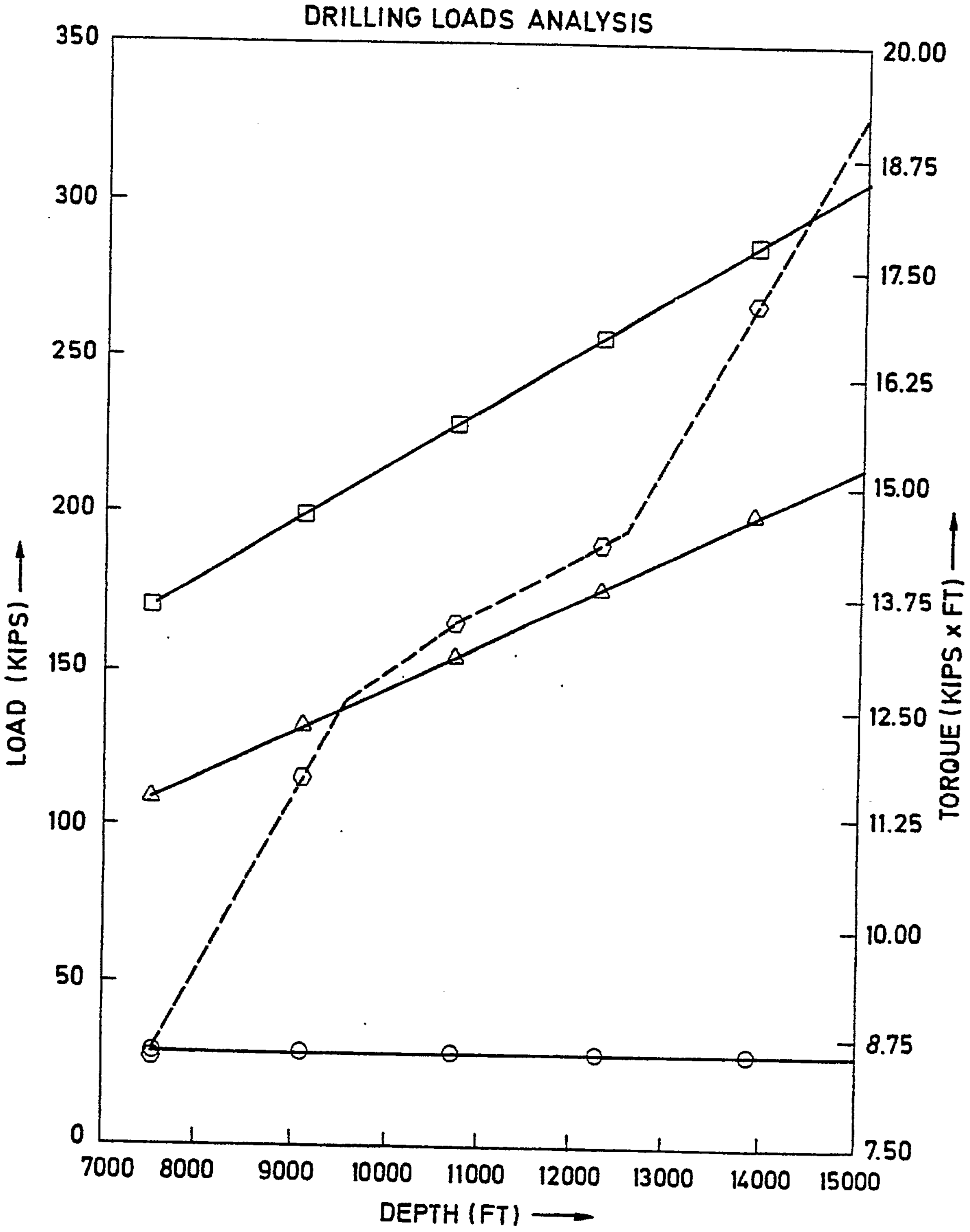


FIG.7

FIG. 9



□ BUOYANT STRING WEIGHT
○ WEIGHT ON BIT
△ ROTATING STRING LOAD
⬡ TORQUE LOSSES